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Exercise Training Increases Baroreceptor Gain Sensitivity in Normal and Hypertensive Rats

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Abstract—Exercise training attenuates arterial hypertension and increases baroreflex sensitivity in spontaneous hypertension. However, no information exists regarding the portion of the baroreflex arch in which this attenuation takes place. We tested the hypothesis that exercise training increases the afferent pathway sensitivity of baroreflex control in both normotensive and spontaneously hypertensive rats (SHR). Arterial pressure and whole-nerve activity of the aortic baroreceptor (multifiber preparation) were evaluated in 30 male rats assigned to 4 groups: sedentary and exercise-trained normotensive rats and sedentary and exercise-trained SHR. Exercise training was performed on a motor treadmill, 5 d/wk for 60 minutes, gradually progressing toward a speed of 26.8 m/min. Exercise training reduced mean arterial pressure in conscious exercise-trained SHR (183 ± 4 versus 165 ± 7 mm Hg). The relation between changes in aortic baroreceptor discharge and changes in systolic arterial pressure increased significantly in exercise-trained normotensive rats (2.09 ± 0.1 versus $1.44 \pm 0.1\%/mm$ Hg) and exercise-trained SHR (0.92 ± 0.1 versus $0.71 \pm 0.1\%/mm$ Hg) compared with their respective sedentary rats. Likewise, the average aortic baroreceptor gain sensitivity (calculated by logistic equation) was significantly higher in exercise-trained normotensive rats (2.25 ± 0.19 versus $1.77 \pm 0.03\%/mm$ Hg) and exercise-trained SHR (1.07 ± 0.04 versus $0.82 \pm 0.05\%/mm$ Hg) compared with their respective sedentary control rats. In conclusion, exercise training increases aortic baroreceptor gain sensitivity in normotensive and SHR, thus improving baroreceptor sensitivity, which may result in a more efficient arterial pressure regulation by the baroreflexes. (*Hypertension*. 2000;36:1018-1022.)

Key Words: exercise ■ baroreceptors ■ hypertension, arterial

Impairment of the baroreflex, associated with depression in afferent baroreceptor activity, is frequently observed in hypertension, atherosclerosis, and aging; these changes have been attributed to mechanoelastic alterations as well as ionic and paracrine factors (for references, see Chapleau et al¹). In spontaneously hypertensive rats (SHR), resetting of the baroreceptor with depressed sensitivity is observed.² We have demonstrated that exercise training improves both the depressed baroreflex control of heart rate and reduces the level of arterial hypertension in SHR. After a 12-week period of low-intensity exercise training, the baroreflex sensitivity to bradycardia and tachycardia returned to near-normal values.³ However, the experimental approach used in that study allowed no conclusion regarding the portion of the reflex arch in which the exercise training acted to improve baroreflex sensitivity. Because afferent baroreceptor sensitivity is impaired in SHR,² we hypothesize that exercise training may compensate for this impairment and thus improve baroreceptor sensitivity. Indeed, exercise training increases brachial

and femoral artery compliance,^{4,5} which may alter baroreceptor sensitivity. Exercise training also induces an increase in the vasodilatory response to acetylcholine in SHR⁶ by releasing endothelial factors that act on the baroreceptor. Moreover, in some pathophysiological conditions (eg, heart failure), the attenuation in baroreflex sensitivity is due to an impairment in the aortic baroreceptor sensitivity.^{7,8}

Therefore, to test the hypothesis that the afferent pathway of the baroreflex is involved in the increase in baroreflex sensitivity after exercise training, we studied the effects of low-intensity exercise training on the aortic baroreceptor gain sensitivity in normotensive rats and SHR.

Methods

Animal Care and Exercise Training Protocol

Sixteen male Wistar rats and 14 SHR (Medical School, University of São Paulo), weighing 180 to 200 g, were fed standard laboratory chow and water ad libitum while housed (2 to 3 per cage) in a temperature-controlled room (22°C) with a dark-light cycle of 12 to 12 hours. These rats were assigned to 4 groups: sedentary normo-

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tensive ($n=8$), exercise-trained normotensive ($n=8$), sedentary hypertensive ($n=8$), and exercise-trained hypertensive ($n=6$) rats. Exercise training was performed on a motor treadmill 5 days per week for 13 weeks. The rats gradually progressed toward a speed of 26.8 m/min, sustained for 60 minutes at a 15% grade, as described in detail elsewhere.⁹ The sedentary rats were handled every day to become accustomed to the experimental procedures. All procedures were followed in accordance with institutional guidelines.

Measurement of Arterial Pressure

After the last training session, 3 cannulas were implanted into vessels and then tunneled to the back of the rat. Placement sites consisted of the carotid (PE-50) and femoral (PE-10) arteries as well as the jugular vein (PE-50). This surgical procedure was performed under ether anesthesia 1 day before the experimental protocol. The arterial pressure was monitored in conscious rats by connecting the carotid artery cannula to a strain-gauge transducer (Statham P₂₃ Db). For direct arterial pressure measurements, the transducer signal was fed to an amplifier (GPA-4 model 2, Stemtech, Inc) and further to a 10-byte analog-to-digital converter (DataQ Instruments, Inc), which was interfaced to a computer (Gateway 2000, Pentium 133 MHz). The arterial pressure was analyzed on a beat-to-beat basis at a frequency of 100 Hz. The heart rate was obtained from arterial blood pressure pulses.

Aortic Baroreceptor Recording: Multifiber Preparation

One day after the measurement of basal arterial pressure, the rats were anesthetized with sodium pentobarbital (30 mg/kg) to permit recording of the arterial pressure and whole-nerve activity of the aortic baroreceptor. The level of anesthesia was adjusted to maintain the blood pressure near the values existing in the conscious state. Aortic fibers of the isolated left aortic nerve or an isolated branch of the left recurrent laryngeal nerve in the lower part of the neck were studied. There was no apparent difference in the results obtained from these two nerve fiber preparations.

The pressure–nerve activity relation, spanning low to high pressures, was measured during rapid changes in arterial pressure (10 to 15 seconds) induced by the withdrawal or infusion of blood (≈ 2.0 mL) into the femoral artery. The arterial pressure (carotid artery) and baroreceptor activity were continuously monitored on an oscilloscope (Tektronix Storage Oscilloscope 5115) and simultaneously recorded on a tape recorder (Hewlett-Packard, 3960) for analysis. To quantify the whole-nerve activity, the nerve traffic was amplified (5A22N Differential Amplifier, Tektronix), full-wave rectified, and further integrated in an AT/CODAS acquisition system (10-kHz frequency), with the arterial pressure wave used as a trigger. Background noise was determined when the nerve activity was suppressed by decreasing arterial pressure with sodium nitroprusside. To allow comparisons among different groups of rats, aortic baroreceptor activity was expressed as a percentage of the maximal nerve activity (100% saturation).

Assessment of Arterial Pressure and Baroreceptor Nerve Activity Relation

Two approaches were used to evaluate the arterial pressure–nerve activity relation in sedentary and exercise-trained rats. The first approach consisted of a descriptive analysis of (1) the average values of SP_{th} , defined as the systolic pressure at which the baroreceptors initiated firing; (2) the average values of SP_{st} , that is, the pressure level at which continuous baroreceptor discharge was achieved during a rapid increase in arterial pressure; (3) the full arterial pressure range for baroreceptor activation, defined by the difference between SP_{st} and SP_{th} ; and (4) the calculated relation between changes in baroreceptor discharge (0% to 100%) and systolic arterial pressure (SAP) (SP_{st} minus SP_{th}) (expressed as %/mm Hg). The second approach consisted of fitting the experimental data to a logistic sigmoid function, as previously described by others.¹⁰ This equation was adapted to fit the relation of SAP–baroreceptor activity that showed a high determination coefficient of $0.97 \pm 2\%$. The

logistic equation was analyzed as follows: Baroreceptor activity = $P_1 + \{ (P_2) / (1 + \exp [P_3(P_4 - SAP)]) \}$, in which P_1 is the maximum response of baroreceptor activity; P_2 , the range of baroreceptor activity (maximum response minus minimum response, %); P_3 , the coefficient to calculate the gain as a function of pressure; P_4 , the BP_{50} , the mean arterial pressure at half of the range of baroreceptor activity; and SAP. The average gain or slope of the curve between two inflection points was given by the following equation: $Gain = P_2 / (P_3 / 4.562)$.

Statistical Analysis

A 2-way ANOVA test for unpaired measurements was used to compare values from the basal levels of arterial pressure and heart rate and from the descriptive and the logistic analysis of baroreceptor function of aortic baroreceptor gain sensitivity to determine the effects of exercise training in normotensive rats and SHR. A value of $P \leq 0.05$ was considered significant. Data are reported as mean \pm SEM.

Results

Basal Levels of Arterial Pressure and Heart Rate

Systolic, diastolic, and mean arterial pressures were similar between sedentary rats and exercise-trained normotensive rats (129 ± 2 versus 130 ± 1 ; 105 ± 1 versus 102 ± 2 and 115 ± 4 versus 113 ± 3 mm Hg, respectively). In SHR, however, systolic, diastolic, and mean arterial pressures were significantly lower in the exercise-trained group compared with the sedentary group (192 ± 9 versus 209 ± 6 ; 140 ± 6 versus 158 ± 3 ; and 165 ± 7 versus 183 ± 4 mm Hg, respectively, $P < 0.05$). Heart rate was significantly lower in the exercise-trained normotensive and SHR groups than in their respective sedentary groups (309 ± 4 versus 340 ± 3 bpm in normotensive rats, and 345 ± 20 versus 383 ± 10 bpm in SHR, respectively).

Aortic Baroreceptor Sensitivity

In normotensive rats, SAP was similar between the anesthetized and conscious conditions (128 ± 3 versus 129 ± 2 mm Hg in sedentary rats, and 128 ± 1 versus 130 ± 1 mm Hg in exercise-trained rats, respectively) as well as in SHR (196 ± 7 versus 209 ± 6 in sedentary rats and 199 ± 10 versus 192 ± 9 mm Hg in exercise-trained rats, respectively). These results show that the decreased arterial pressure observed in conscious exercise-trained SHR was no longer observed after anesthetization. Similarly, heart rate tended to be lower after anesthesia, so the significant difference between sedentary and exercise-trained groups observed in the conscious state was no longer observed (383 ± 9 versus 361 ± 9 bpm in SHR, and 280 ± 14 versus 285 ± 09 bpm in normotensive rats, respectively).

The Table shows the descriptive analysis of aortic baroreceptor function in normotensive rats and SHR. Exercise training did not change the systolic pressure threshold in normotensive rats or SHR. However, exercise training did significantly reduce the systolic pressure saturation and full arterial pressure range for baroreceptor activation in normotensive rats and SHR. In addition, an increased relation between changes in baroreceptor discharge and changes in SAP (%/mm Hg) was found in exercise-trained normotensive rats and SHR compared with their respective sedentary rat groups.

Hemodynamic and Baroreceptor Function Curve Parameters in Normotensive Rats and SHR

	SAP, mm Hg	DAP, mm Hg	MAP, mm Hg	SP _{th} , mm Hg	SP _{st} , mm Hg	Range, mm Hg	HR, bpm	Index, %/mm Hg
NS	128±3	108±2	118±2	105±2	175±3	71±4	383±9	1.47±0.10
NT	128±1	109±1	119±1	107±3	157±2*	49±3*	361±9	2.03±0.16*
HS	200±5	150±4	129±3	129±3	273±9†	144±9†	280±14	0.71±0.04†
HT	194±6	154±5	133±5	133±5	244±11*	122±8*	285±9	0.92±0.05*

NS indicates sedentary normotensive rats; NT, exercise-trained normotensive rats; HS, sedentary SHR; HT, exercise-trained SHR; SAP, DAP, and MAP, systolic, diastolic, and mean arterial pressure, respectively; and HR, heart rate.

Exercise training did not change systolic pressure threshold (SP_{th}) in normotensive and SHR. In contrast, exercise training significantly reduced systolic pressure saturation (SP_{st}) and the full arterial pressure range for baroreceptor activation in both normotensive rats and SHR. Data are mean±SEM.

*Significant difference, sedentary and exercise-trained rats, $P \leq 0.05$.

†Significant difference when compared with NS, $P \leq 0.05$.

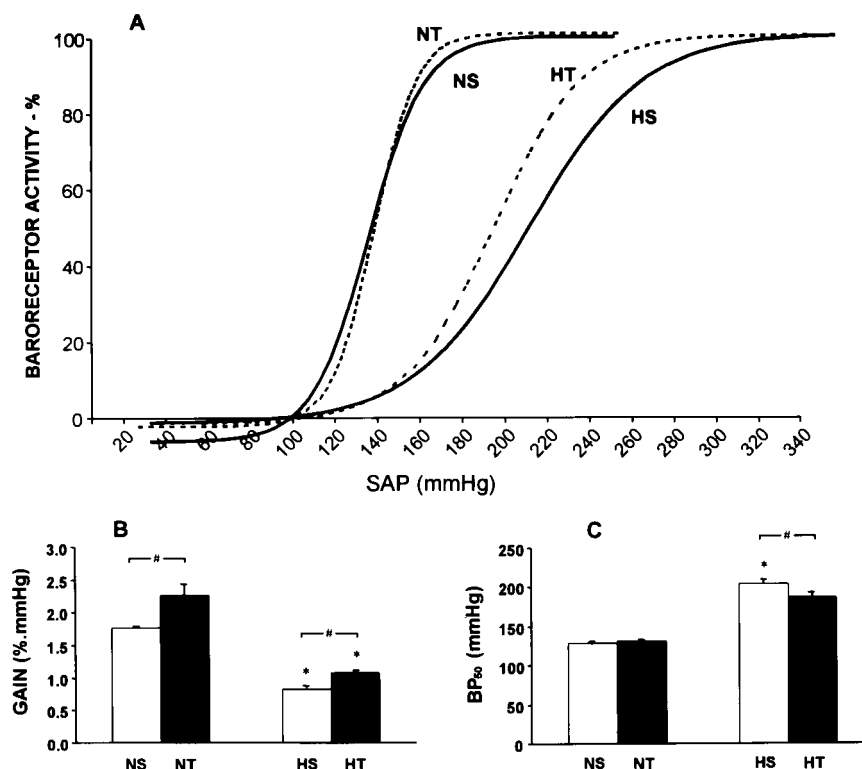
The Figure shows the logistic equation used to calculate the baroreceptor activity–SAP relation, the average gain, and the BP₅₀ in sedentary and exercise-trained normotensive and SHR. In normotensive rats, the BP₅₀ did not significantly differ between sedentary and exercise-trained rats (panel C; 128±1 versus 131±1 mm Hg, respectively). However, the average gain was significantly increased (27%) in exercise-trained normotensive rats compared with sedentary normotensive rats (panel B; 2.25±0.19 versus 1.77±0.03%/mm Hg, respectively). In SHR, exercise training significantly decreased the BP₅₀ (panel C; 187±5 versus 204±5 mm Hg in exercise-trained and sedentary rats, respectively) and significantly increased (30%) the average gain (panel B; 1.07±0.04 versus 0.82±0.05%/mm Hg in exercise-trained and sedentary rats, respectively).

Discussion

The main and new finding in the present study is that dynamic exercise training increases the gain sensitivity of aortic

baroreceptor function in normotensive rats and SHR. Bradycardia has been considered a good marker for exercise training adaptation in both normotensive¹¹ and SHR¹²; thus, its presence in the conscious exercise-trained normotensive rats and SHR demonstrates the effectiveness of the exercise training used in the present study. We also found that exercise training significantly reduced arterial pressures in SHR. This finding confirms the results of our previous study¹² in which we demonstrated that low-intensity exercise training decreases arterial pressures in SHR.

As we have thought, exercise training increases baroreceptor gain sensitivity in SHR, which has 2 pathophysiological implications. First, exercise training substantially improved aortic baroreceptor gain sensitivity in SHR, which is 40% depressed after the resetting of aortic baroreceptors in established hypertension.^{13,14} Second, the increase in baroreceptor discharge in exercise-trained SHR explains, at least in part, the 150% increase in baroreflex bradycardia and the 67%



Average parameters of baroreceptor activity–SAP relation obtained by logistic sigmoid equation (A), average gain (B), and BP₅₀ (C) in sedentary (NS) and exercise-trained (NT) normotensive rats and sedentary (HS) and exercise-trained (HT) SHR. Data are mean±SEM. Note that exercise training improves aortic baroreceptor gain sensitivity in both normotensive rats and SHR. However, exercise training restores only part of aortic baroreceptor gain sensitivity in HT; baroreceptor gain sensitivity is lower in HT than NS (see B). *Significant difference when compared with NS, $P \leq 0.05$. #Significant difference between sedentary rats and exercise-trained rats, $P \leq 0.05$.

increase in baroreflex tachycardia (which were depressed in sedentary SHR) observed in our previous study.³ Moreover, the central command or efferent pathway of the baroreflex also may participate in this exercise-induced increase in baroreflex sensitivity in SHR.

The present study shows that the effect of low-intensity exercise training on aortic baroreceptor gain sensitivity is not restricted to SHR but also occurs in normotensive rats. This exercise training adaptation may play a role in the increased baroreflex tachycardia reported by us in a previous study.¹⁵ Surprising, however, was the fact that exercise training did not increase baroreflex bradycardia in normotensive rats. The discrepancy between the positive effect of exercise training on aortic baroreceptor gain sensitivity and the depressed baroreflex bradycardia can be explained by other alterations occurring along the entire reflex arch. Chen et al¹⁶ observed an attenuation of baroreflex tachycardia in response to induced changes in arterial pressure in anesthetized rats that had been submitted to daily spontaneous running. Because the baroreceptor gain sensitivity was similar in exercise-trained and sedentary rats, they attributed the baroreflex attenuation to changes in the central component of the reflex rather than a change in baroreceptor discharges. Alternatively, the attenuation in baroreflex bradycardia may take place in the efferent pathway of the reflex arch. In fact, in a previous study,¹¹ we found decreased bradycardiac responses to progressive stimulation of efferent fibers of the vagal nerve and increasing doses of methacholine in exercise-trained rats. In addition, we demonstrated a decrease in the intrinsic heart rate in exercise-trained normotensive rats, suggesting a sinus node change after exercise training. Thus, the attenuation in baroreflex bradycardia during arterial pressure increases in exercise-trained rats may be explained by a decreased sensitivity of the pacemaker cells, which overcomes the increased sensitivity of baroreceptor function.¹⁷

The mechanisms involved in the increased afferent baroreceptor sensitivity after exercise training were not addressed in the present study. However, some potential mechanisms may explain the increased baroreceptor gain sensitivity after exercise training presently observed. According to the mechanoelastic concept, in the presence of increased vascular compliance, the same pulse pressure can result in increased baroreceptor activation.¹⁸ Because exercise training increases intrinsic aortic compliance in rats¹⁹ and arterial compliance^{20,21} in humans, we postulate that the improvement in aortic baroreceptor gain sensitivity may be due to an increase in aortic compliance. Although the increase in arterial compliance is an attractive explanation for the enhancement of baroreceptor gain sensitivity produced by exercise training, it appears to apply to normotensive but not hypertensive rats. This conclusion is based on the observation by Kingwell et al²² that exercise training does not increase arterial compliance in SHR. Endothelial changes after exercise training is another attractive hypothesis to explain the increase in aortic baroreceptor gain sensitivity found in the present study. Both the magnitude and frequency of shear stress on the endothelial cells during exercise increase the release of endothelial factors and/or the sensitivity of endothelial cells, which in turn enhances baroreceptor ending activity.²⁰ In fact, Yen et

al⁶ reported that exercise training increases the vasodilatory response to acetylcholine in SHR. The increase in aortic baroreceptor gain sensitivity may be also explained by a reduction nerve sympathetic nerve activity. Exercise training reduces muscle sympathetic nerve activity²³ and the spillover of norepinephrine²⁴ in humans and reduces the renal sympathetic nerve activity in rats.¹⁷ These changes in sympathetic nerve activity could modify the distensibility of the sinus area^{25–27} and, in consequence, improve afferent baroreceptor discharge in SHR. Alternatively, someone could raise the question that the blood withdrawal or infusion used in the present study could alter the activity of cardiopulmonary receptor and thus affect the aortic baroreceptor gain sensitivity by interaction of reflex influences. However, this does not appear to be the case. During hypotension/deactivation of cardiopulmonary receptors and hence increase in sympathetic nerve activity, no difference in the pressure threshold values (Table) was found between sedentary and exercise-trained rats. The marked difference in the gain sensitivity of the afferent baroreceptor in both normotensive and hypertensive rats was detected mostly in the upper part of baroreceptor function curve.

In conclusion, low-intensity exercise training improves aortic baroreceptor gain sensitivity, which explains, at least in part, the increased baroreflex control after exercise training in SHR. Furthermore, these exercise-training induced changes in baroreflex sensitivity may have important implications in buffering arterial pressure variations, given the reduced buffering capacity associated with hypertension.

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References

1. Chappleau MW, Cunningham T, Sullivan MJ, Wachtel RE, Abboud FM. Structural versus functional modulation of the arterial baroreflex. *Hypertension*. 1995;26:341–347.
2. Andresen MC, Yang M. Arterial baroreceptor resetting contributions of chronic and acute processes. *Clin Exp Pharmacol Physiol*. 1989;15:19–30.
3. Silva GJJ, Brum PC, Negrão CE, Krieger EM. Acute and chronic effects of exercise on baroreflexes in spontaneously hypertensive rats. *Hypertension*. 1997;30:714–719.
4. Giannattasio C, Cattaneo BM, Mangoni AA, Carugo S, Sampieri L, Cuspidi C, Grassi G, Mancia G. Change in arterial compliance induced by physical training in hammer-throwers. *J Hypertens*. 1992;10:S53–S55.
5. Kool MJF, Struijker-Boudier HA, Wijnen JA, Hoeks A, Bortel LM. Effects of diurnal variability and exercise training on properties of large arteries. *J Hypertens*. 1992;10:S49–S52.
6. Yen MH, Yang JH, Sheu JR, Lee YM, Ding YA. Chronic exercise enhances endothelium-mediated dilation in spontaneously hypertensive rats. *Life Sci*. 1995;57:2205–2213.
7. Ellenbogen KA, Mohanty PK, Szentpetery S, Thames MD. Arterial baroreflex abnormalities in heart failure: reversal after orthotopic cardiac transplantation. *Circulation*. 1989;79:51–58.
8. Zucker IH, Wang W, Brandle M, Schultz HD, Patel KP. Neural regulation of sympathetic nerve activity in heart failure. *Prog Cardiovasc Dis*. 1995;34:397–414.

9. Negrão CE, Ji LL, Schauer JE, Nagle FJ, Lardy HA. Carnitine supplementation and depletion: tissue carnitines and enzymes in fatty acid oxidation. *J Appl Physiol.* 1987;63:315–321.
10. Head GA, McCarty R. Vagal and sympathetic components of the heart rate range and gain of the baroreceptor-heart rate reflex in conscious rats. *J Auton Nerv Syst.* 1987;21:203–213.
11. Negrão CE, Moreira ED, Santos MCLM, Farah VMA, Krieger EM. Vagal function impairment after exercise training. *J Appl Physiol.* 1992;72:1749–1753.
12. Vêras-Silva AS, Mattos KC, Gava NS, Brum PC, Negrão CE, Krieger EM. Low-intensity exercise training decreases cardiac output and hypertension in spontaneously hypertensive rats. *Am J Physiol.* 1997;276:H2627–H2631.
13. Moreira ED, Ida F, Krieger EM. Reversibility of hyposensitivity during reversal of hypertension. *Hypertension.* 1990;15:791–796.
14. Moreira ED, Ida F, Krieger EM. Early depression of the baroreceptor sensitivity during onset of hypertension. *Hypertension.* 1992;19(suppl 2):II-198-II-201.
15. Krieger EM, Brum PC, Negrão CE. Role of arterial baroreceptor function on cardiovascular adjustments to acute and chronic dynamic exercise. *Biol Res.* 1998;31(suppl 3):273–279.
16. Chen CY, DiCarlo SE, Scislo TJ. Daily spontaneous running attenuated the central gain of the arterial baroreflex. *Am J Physiol.* 1995;268:H662–H669.
17. Negrão CE, Irigoyen MC, Moreira ED, Brum PC, Freire PM, Krieger EM. Effect of exercise training on RSNA, baroreflex control, and blood pressure responsiveness. *Am J Physiol.* 1993;265:R365–R370.
18. Kirchheim HR. Systemic arterial baroreceptor reflexes. *Physiol Rev.* 1976;56:100–176.
19. Kingwell BA, Arnold PJ, Jennings GL, Dart AM. Spontaneous running increases aortic compliance in Wistar-Kyoto rats. *Cardiovasc Res.* 1997;35:132–137.
20. Cameron JD, Dart AM. Exercise training increases total systemic arterial compliance in humans. *Am J Physiol.* 1994;266:H693–H701.
21. Kingwell BA, Cameron JD, Gillies KJ, Jennings GL, Dart AM. Arterial compliance may influence baroreflex function in athletes and hypertensives. *Am J Physiol.* 1995;268:H411–H418.
22. Kingwell BA, Arnold PJ, Jennings GL, Dart AM. The effects of voluntary running on cardiac mass and aortic compliance in Wistar-Kyoto and spontaneously hypertensive rats. *J Hypertens.* 1998;16:181–185.
23. Grassi G, Seravalle G, Calhoun DA, Mancia G. Physical training and baroreceptor control of sympathetic nerve activity in humans. *Hypertension.* 1994;23:294–301.
24. Meredith IT, Friberg P, Jennings GL. Exercise training lowers resting renal but not cardiac sympathetic activity in man. *Hypertension.* 1991;18:575–582.
25. Bagshaw RJ, Peterson LH. Sympathetic control of the mechanical properties of the canine carotid sinus. *Am J Physiol.* 1972;222:1462–1468.
26. Bolter CP, Ledsome JR. Effect of cervical sympathetic nerve stimulation on canine carotid sinus reflex. *Am J Physiol.* 1976;230:1026–1030.
27. Seagard JL, Hopp FA, Kampine JP. Effect of sympathetic sensitization of baroreceptors on renal nerve activity. *Am J Physiol.* 1987;252:R328–R335.